The role of science in resolution of environmental crises at Kesterson Reservoir and Mono Lake, California

Nigel W. T. Quinn[1] and Peter T. Vorster[2]
[1]Staff Geological Scientist, Lawrence Berkeley National Laboratory, Bld 70 A-3317K, Berkeley, California 94720, USA and
[2]Hydrologic Consultant, 3901 Balfour Ave, Oakland, California 94610, USA

Abstract

Two events in California's recent history have had a profound impact in shaping present and future water resources policy: the selenium contamination at Kesterson Reservoir and the battle to save Mono Lake. The irrigation-induced selenium toxicity discovered at Kesterson changed public perception of agriculture as a benign consumer of water, eroded the political power of the agricultural lobby, and has contributed to a revision in the allocation of water between the cities, agriculture and the environment. The Mono Lake Decisions of 1983 and 1994 set an equally important precedent in affirming the State's public trust obligation to preserve public resources and to reconsider previous water right allocations in the light of evolving knowledge and changing priorities. Both of these issues were important precursors for the current multi-billion dollar State and Federal (CALFED) initiative to 'fix' the myriad of biologic, hydrologic and water quality problems of the San Francisco Bay estuary. In this paper, we compare the Kesterson and Mono Lake controversies and discuss the role of science and research in attempting to resolve these issues. We conclude by drawing linkages to the current CALFED initiative and suggesting implications for future water quality management in California's lakes and reservoirs.

Key words

California water resources, drainage, Kesterson, Mono Lake, selenium, water diversion.

SELENIUM TOXICOSIS AT KESTERSON RESERVOIR

Kesterson Reservoir was initially designed as a flow regulating facility on the San Luis Drain for export of saline agricultural drainage from the west side of the San Joaquin Valley, California. Budgetary problems and planning conflicts resulted in the completion of only 135 km of the 200 km salt export facility when it opened in 1980 providing a drainage service initially to a 2000 ha area within a 450 000 ha area requiring a drainage outlet to the ocean. The US Fish and Wildlife Service, recognizing the value of additional potential waterfowl habitat on the Pacific Flyway, assumed combined operation of the reservoir. During Kesterson Reservoir's operation between 1981 and 1986 approximately 9000 kg of selenium and 3×10^8 kg of salts were discharged into 12 ponds. Kesterson Reservoir was closed in 1986 when nesting failure and selenium teratogenicity was observed in resident wildfowl (Fig. 1). Images of malformed duck embryos galvanized the environmental community and led the federal government to initiate multi-million dollar research, monitoring and planning programmes to remediate Kesterson Reservoir and to develop solutions to regional selenium drainage problems. Research at Kesterson Reservoir focused upon actions to immobilize selenium in the groundwater system, reduce the inventory of the reservoir sediments and minimize wildlife exposure to selenium.

Selenium is a naturally occurring trace element present in many soils derived from marine sedimentary deposits and is ubiquitous in the western USA. Selenium is unique in having a narrow concentration bandwidth between its functions as an essential nutrient and as a toxin in humans. Neither the ecological risk of increased selenium concentration levels to waterfowl and other biota nor the geochemical transport modalities were well understood in 1983 when Federal scientists observed the first malformed embryos.

Accepted for publication 1 August 1998.

Eleven years later, though the scientific literature is rich with reports of field and laboratory studies, the biogeochemistry of selenium in natural river, wetland and lake ecosystems is still incompletely understood. Technologies for cost-effective reduction or removal of selenium from agricultural drainage, municipal and industrial return flows are still not well developed.

Political pressure to reduce the ecological hazard at Kesterson Reservoir and in other wildlife refuges throughout the western USA that received selenium contaminated drainage water was intense. Although a number of highly relevant scientific research projects was initiated to address the data needs of policy-makers, these studies were neither able to respond quickly enough or to offer the level of certainty needed to influence the ultimate remediation decision at the Kesterson site. Clean fill material was transported to the Kesterson site and spread over the ponds to increase the depth to groundwater and reduce wildlife exposure to evaporatively concentrated soluble selenium at the soil surface. Results from the research studies confirmed the low risk of selenium plume migration within the groundwater aquifer and the reduced risk of wildlife exposure to selenium with the addition of fill material. Soil bioremediation experiments utilizing fungi to methylate soil selenium to a volatile gas were initially encouraging but eventually proved to be insufficiently cost-effective as a long-term selenium dissipation strategy. A flexible geochemical immobilization strategy, which was more cost-effective and which would have required maintaining an anoxic environment in the pond sediments, was not implemented. More recent research into biological treatment technologies has demonstrated the soundness of this strategy in immobilizing selenium.

Although the selenium-induced drainage crisis at Kesterson Reservoir is widely regarded as an environmental disaster, it was also a fortuitous early warning that may have averted a more serious problem in later years had the drain been completed and had the Bay-Delta ecosystem received agricultural drainage from the entire west-side of the San Joaquin Valley.

PRESERVATION OF MONO LAKE

Mono Lake is one of oldest bodies of water in the western USA, located just east of Yosemite National Park in the Eastern Sierra at an elevation of about 1945 m (Fig. 2). This hypersaline, high altitude, terminal lake has a mean depth of 18 m and attracts 80 species of migratory water birds and large numbers of species of gull, grebe, duck and shore bird as well as providing a nursery for about 85% of the California gull (*Larus californicus*) population. Phalaropes and grebes rely on the lake's abundant brine shrimp and brine flies during their annual migration to wintering areas in South America. The brine shrimp and brine flies feed on algae and provide a rich diet for the visiting waterfowl.

The City of Los Angeles was granted permits for appropriation of water from the tributary streams in 1940 and diverted increasing amounts of flow until, by 1970, most of the inflow to the lake was diverted. From 1970 to 1982, an average of about 123 million $m^3 y^{-1}$ was diverted. Diversions between 1940 and 1982 were directly responsible for a 14 m drop in the water surface elevation, thus reducing the lake surface area by approximately 33% and doubling the salinity of the water (Hart 1996). The receding lake surface caused land bridges to be formed to islands allowing predators to disturb nesting birds and eventually eliminate

Fig. 1. Newspaper reporter next to one of the wetland ponds at Kesterson Reservoir after the news broke concerning selenium teratogenicity in wildfowl.

nesting colonies. Scientists monitoring the brine shrimp population observed a decline of 85–95% by the time the salinity of the lake water approached 97 000 mg L^{-1}. Laboratory studies suggested that if concentrations approached 150 000 mg L^{-1} total elimination of the brine shrimp and brine fly larvae populations would occur (Hart 1996). Other scientists reported that riparian and freshwater habitats were being lost due to erosion and desiccation as in-stream water flows were reduced; not surprisingly, the thriving (although non-native) trout populations disappeared. Local air pollution officials affirmed that the increased size and frequency of dust-storms on the east and north sides of the lake, induced by salt efflorescence from exposed lakebeds, violated air quality standards as exposure was increased to arsenic and other toxins in the dust. Although previously submerged tufa formations were exposed to public view for the first time as the lake level dropped, it was observed that wave action was beginning to erode the sediment around the fragile base of some of the tufa towers causing them to collapse. Young scientists inspired by the unusual lake and landscape produced a significant literature of research findings and observations that provided essential information for litigation, spearheaded by the Mono Lake Committee, the National Audubon Society and California Trout.

In 1983, a landmark legal decision was reached, 4 years after the initial lawsuit was filed by the National Audubon Society. This recognized Mono Lake as a 'scenic and national treasure of national significance', and furnished the State with the power, under the public trust doctrine, to reconsider the City of Los Angeles's previous water right licence. The California Supreme Court found that in lowering water levels in the navigable Mono Lake, the recreational and ecological value of the resource was diminished, and recommended that a responsible body ought to balance the city's requirement for a pristine and inexpensive source of municipal water with the needs of the lake ecosystem. A subsequent court ruled that the city's water licences were invalid because they provided insufficient flow in the streams below the diversion dams to maintain fish in good condition. In 1994, after 11 additional years of legal wrangling and scientific study, the city's water licences were modified by the State Water Resources Control Board to require sufficient flows along each water course to maintain the trout fisheries and restore the lake to an elevation of at least 1948 m, or 5 m above the 1994 lake level.

CHRONOLOGY OF KESTERSON AND MONO LAKE CONTROVERSIES

Comparison of the Kesterson and Mono Lake controversies reveals certain similarities and contrasts. While Kesterson was a man-made impoundment for agricultural drainage generated from irrigation supply water obtained from the western Sierra Nevada mountains, Mono Lake is an ancient terminal lake that drains the watersheds on the volcanically active east side of the Sierra Nevada. The agricultural drainage inflow to Kesterson contained selenium, boron and other salts leached from native soils and contained in native groundwater displaced by irrigation into tile drains. Surface water and groundwater recharge to Mono Lake leaches smaller quantities of salts and minerals such as carbonate, sulfate and chloride and trace quantities of fluoride, arsenic and boron. Evaporation of the high carbonate concentrations in Mono Lake during its long existence has

Fig. 2. Winter at Mono Lake showing the snow-capped eastern Sierra Nevada mountains in the background and Paoha Island in the foreground. The exposed salt flats are visible in the upper right.

produced a brine that is 80 times more alkaline than seawater and with a salinity that is three times greater than that of seawater. These salt concentrations are five to six times higher than those observed at Kesterson Reservoir, a facility that has operated for only 5 years. Although selenium has been measured in the alkali dust clouds to the north and east of Mono Lake since the drop in water level, analyses of lake water show non-detectable concentrations of selenium. Had the lake inflow contained selenium levels similar to those from the Coast Range mountain range to the west of the San Joaquin Valley, the Los Angeles Department of Water and Power diversions might have raised selenium concentrations above the toxic threshold and produced teratogenic impacts to waterfowl similar to those observed at Kesterson. This would likely have changed the course and perhaps the eventual outcome of the Mono Lake controversy.

Although the Mono Lake and Kesterson controversies began in similar ways, largely the result of observations of concerned scientists, the trajectory and final outcome were quite different. While research at the lake was spawned by individuals, mainly students attracted to the simple but highly productive ecosystem and the climatic and geomorphic signatures of the fluctuating hypersaline lake, much of the research at Kesterson was conducted by researchers charged with developing cost-effective remediation strategies by the Federal government. Scientific inquiry was more free-ranging at Mono Lake and was remarkable in its ability to anticipate the issues in the steady flow of public interest litigation. This helped to reduce the level of uncertainty and provided valuable predictive information to the plaintiffs and government policy-makers. Scientific research at Kesterson was largely a rearguard action that failed to inspire the same degree of public confidence or to have the same impact on resolution of the controversy. The manner in which science was carried out in these examples may have been as important as the science itself.

Another example of the free-ranging, private inquiry that distinguishes the Mono Lake example led an individual to follow a legal hunch that the obscure Public Trust Doctrine (a legal artifact, originating from Roman and English common law, previously applied to prevent the filling of tidelands, that guaranteed public access and enjoyment of navigable water bodies) could be extended to a dwindling, but navigable, public resource nourished by non-navigable streams. Pursuit of this theory in the courts created the first collision of two separate systems of natural resource law in the State of California: the appropriative water rights doctrine, which recognizes the private right to use water based on precedence, and the public trust doctrine, which entrusts the state with ultimate management responsibility to ensure public access to and enjoyment of state-owned resources. No such legal manoeuvring challenged resolution of the Kesterson issue; the federal government settled legal claims of property damage by purchasing lands adjacent to Kesterson Reservoir, which were ultimately dedicated to create replacement wetland habitat. The drainage service promised by the federal government to farmers in the San Joaquin Valley has yet to be provided.

While scientific uncertainties still plague an ultimate solution to the drainage disposal problems spawned by the events at Kesterson Reservoir, the Mono Lake dispute has been largely resolved without lasting acrimony. A restoration plan for Mono Lake and its tributary streams was negotiated by the litigants. This provides that the Water Board-mandated inflows to the lake be released in a manner that allows natural processes to restore the habitat and the fisheries in the streams. Diversions to Los Angeles will increase from the current 19.7 to an average of 38 million $m^3 y^{-1}$ (35% of the city's previous long-term yield from the Mono Basin). The Mono Lake Committee, the citizens' group that led the 20 year struggle to preserve the lake, secured federal and state funding for wastewater reclamation projects that will eventually replace the lost supply (Hart 1996).

CONCLUSIONS

Environmental education and public activism in the 1960s and 1970s led to federal water quality legislation and to statutory environmental legislation concerning rivers and lakes in California. In the 1980s the Kesterson and Mono Lake controversies ushered in new paradigms in public perception and in water resources planning. The Mono Lake public trust decision forced the state to reconsider the allocation of water in the Sacramento-San Joaquin River and Delta system for the protection of water quality, and this has directly led to the massive CALFED planning effort to 'fix' the system. Scientists are not only uncovering the basic underlying information but are playing an increasingly important role in helping to resolve conflicts. Even though much of this science is government directed and doctrinaire in its focus, independent scientists working for citizen groups and the universities still play a pivotal role.

REFERENCE

1. Hart J. (1996) *Storm Over Mono. The Mono Lake Battle and the California Water Future*. University of California Press, Berkeley, California, USA.

1Sc and PhD &

Nigel W. T. Quinn is a water resources engineer with a BSc (Hons) degree in irrigation engineering from Silsoe College, and an MS in agricultural and civil engineering from Cornell University. After serving as a principal hydrologist from 1987 ~~and~~ to 1990 for the San Joaquin Valley Drainage Program (a $50 million dollar planning effort to help resolve selenium drainage problems in the western San Joaquin Valley, California) he joined Lawrence Berkeley National Laboratory in 1991. His research at LBNL has focused on selenium bioremediation in natural waterways and wetland systems and on techniques to improve control and management of drainage from agricultural and wetland systems. This research has led to the development of mathematical models and decision support systems that are being used by the US Bureau of Reclamation to assist in management of California's Federal water resources.

Peter T. Vorster has over 20 years experience as a hydrologist primarily focusing on California's water resources. He began his work on California water issues as a principal researcher on the California Water Atlas. Since 1979 he has been a consultant to the Mono Lake Committee on the hydrology and water management of the Mono Basin and Southern California. From 1979 to 1986, he worked for the engineering consulting firm of Philip Williams and Associates, and from 1986 to the current time he has been an independent consultant in hydrology. From 1994 and 1996 he was a lecturer in resource management and environmental studies at California State University at Hayward. Since October 1996 Peter has also been a hydrologist with The Bay Institute, a non-profit research and advocacy organization working on San Francisco Bay-Delta water management and restoration issues. He holds an AB in Geography and Geology, an MA in Geography, and completed his doctoral coursework in Environmental Planning.